

Human Systems Integration in Practice: Constellation Lessons Learned

NASA's Constellation program provided a unique testbed for Human Systems Integration (HSI) as a fundamental element of the Systems Engineering process. Constellation was the first major program to have HSI mandated by NASA's Human Rating document. Proper HSI is critical to the success of any project that relies on humans to function as operators, maintainers, or controllers of a system. HSI improves mission, system and human performance, significantly reduces lifecycle costs, lowers risk and minimizes re-design. Successful HSI begins with sufficient project schedule dedicated to the generation of human systems requirements, but is by no means solely a requirements management process. A top-down systems engineering process that recognizes throughout the organization, human factors as a technical discipline equal to traditional engineering disciplines with authority for the overall system. This partners with a bottoms-up mechanism for human-centered design and technical issue resolution. The Constellation Human Systems Integration Group (HSIG) was a part of the Systems Engineering and Integration (SE&I) organization within the program office, and existed alongside similar groups such as Flight Performance, Environments & Constraints, and Integrated Loads, Structures and Mechanisms. While the HSIG successfully managed, via influence leadership, a down-and-in Community of Practice to facilitate technical integration and issue resolution, it lacked parallel top-down authority to drive integrated design. This presentation will discuss how HSI was applied to Constellation, the lessons learned and best practices it revealed, and recommendations to future NASA program and project managers. This presentation will discuss how Human Systems Integration (HSI) was applied to NASA's Constellation program, the lessons learned and best practices it revealed, and recommendations to future NASA program and project managers on how to accomplish this critical function.



Human Systems Integration (HSI)

In Practice: Constellation (CxP) Lessons Learned

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Human Systems Integration (HSI) in Practice

Goal of this presentation:

- Discuss forward steps towards implementing the HSI process at NASA based on lessons learned from their application to the Constellation (CxP) program.

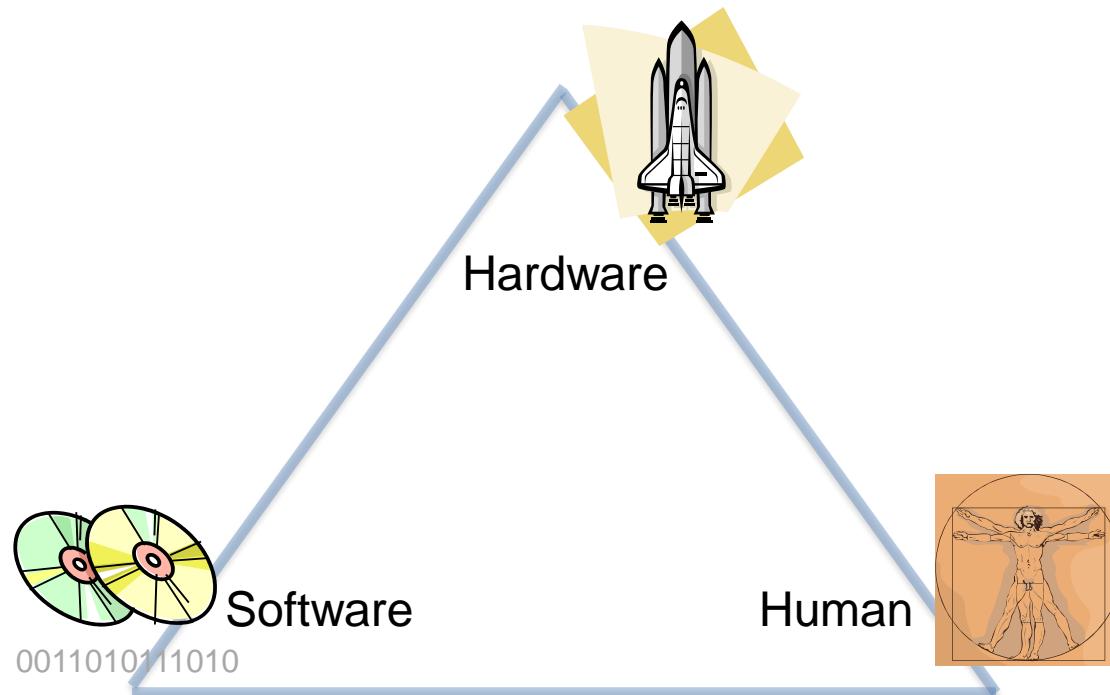
Overview:

- What is HSI?
- HSI in Systems Engineering
- Lessons Learned and Best Practices from CxP
- Next Steps



What is Human Systems Integration?

HSI is the process by which human capabilities and limitations are effectively and affordably integrated with system design and development



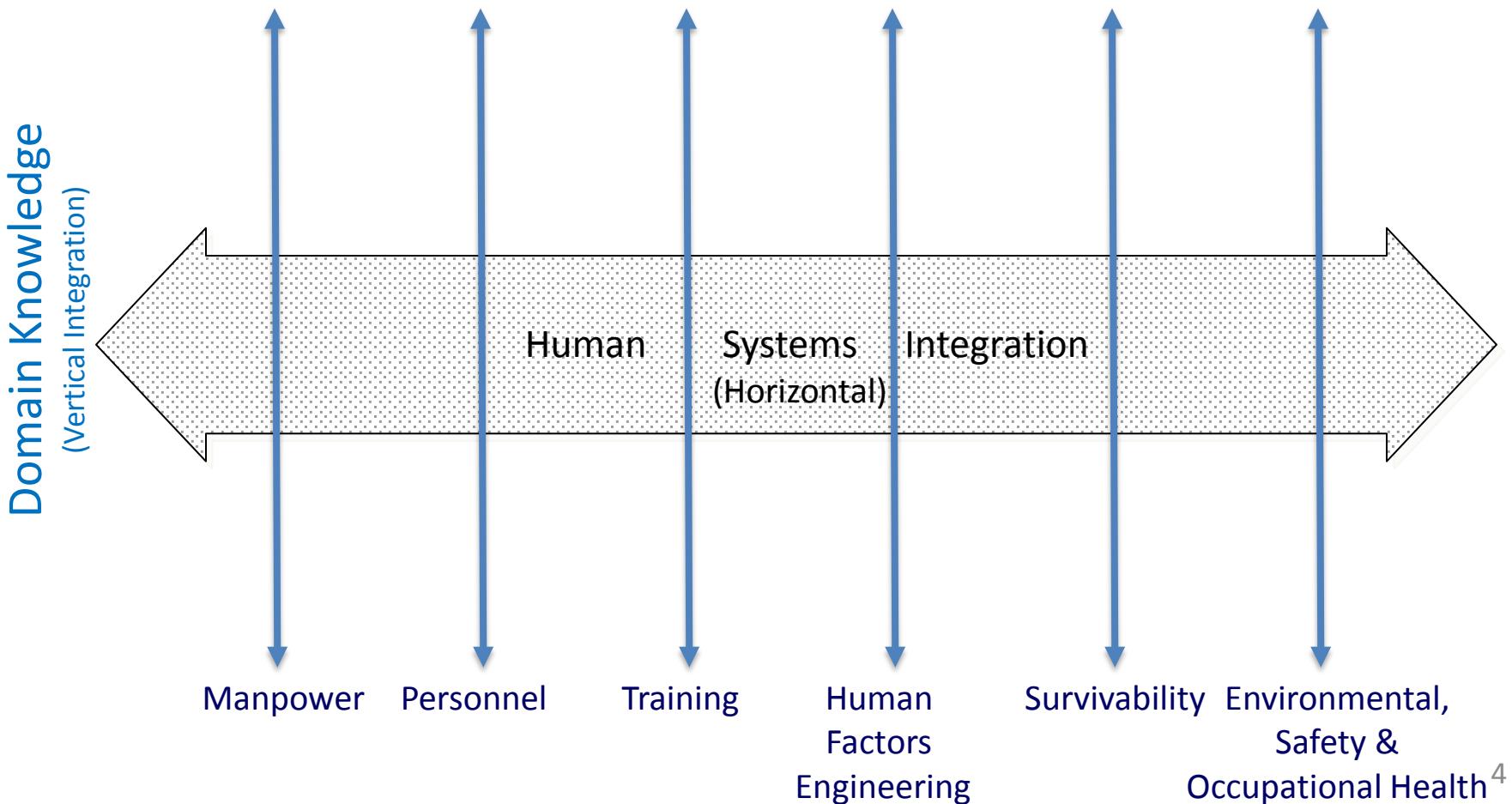
HSI is design with human concerns treated equal to systems concerns



What is Human Systems Integration? (cont'd)

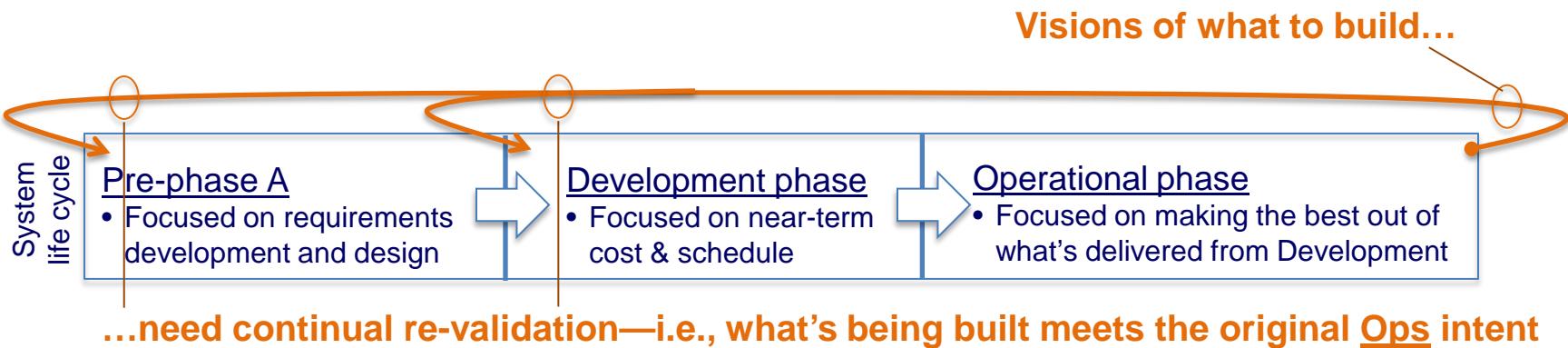
Horizontal integration of the human system domains

- Coordinate to help diverse specialists understand each other's languages, metrics and concerns





What is Human Systems Integration? (cont'd)



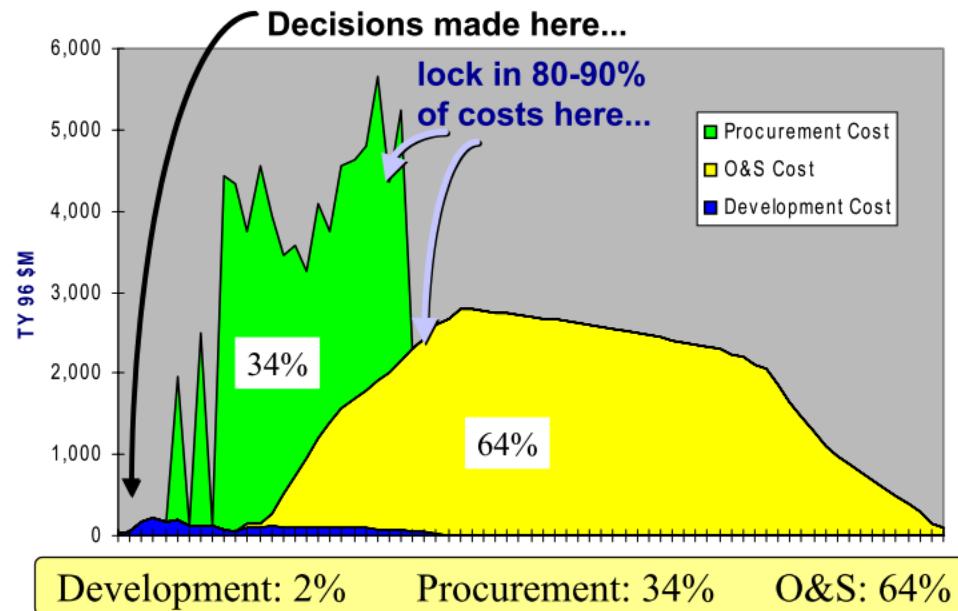
- HSI systematically infuses the needs of all users into the earliest stages of Development
 - I.e., HSI continually validates the original intent
 - The DoD mandates HSI as a means to produce cost-effective products that meet operations objectives and reduce Ops era costs
- HSI supports the experience of all users: ground control, maintenance, logistics,...down to shipping & receiving



HSI in the Department of Defense (DoD)

The Department of Defense (DoD) has made HSI Mandatory:

- The DoD found that ±80% of new systems' costs occur after Development

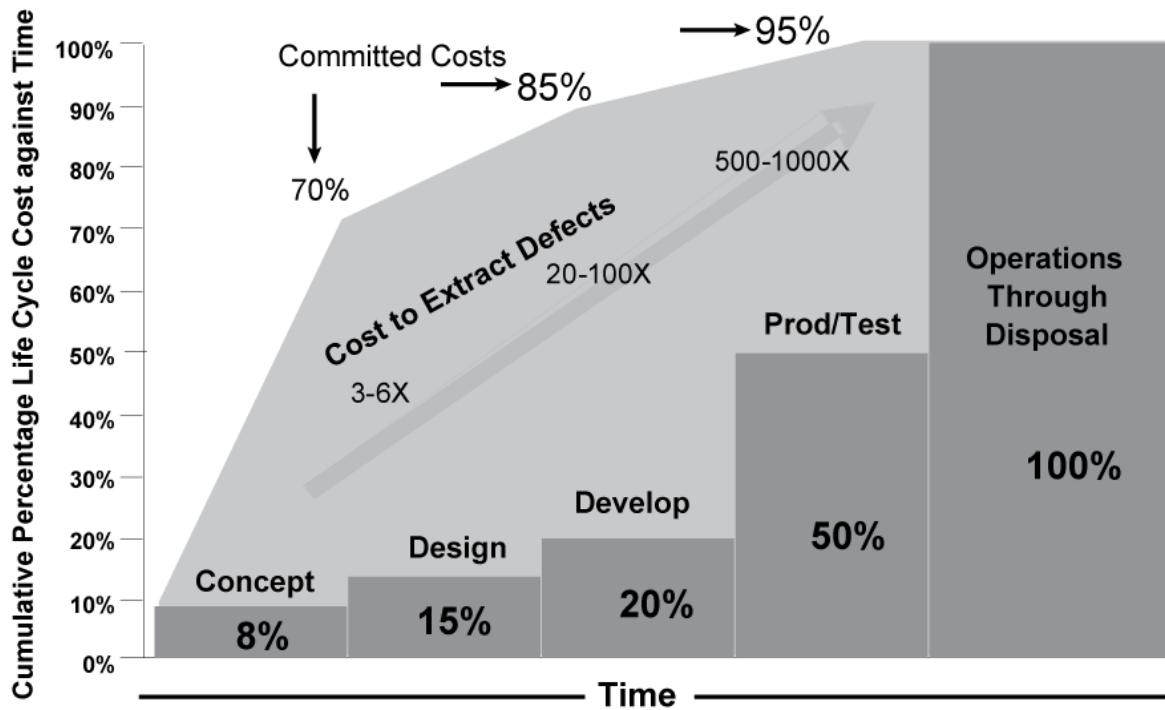


- Fig 1 (Ref)
- Major Ops Era costs are human-related: Manpower, Personnel, Training
 - Rework of human/system interfaces
 - Logistics and Maintenance
 - Poor human/system performance



Cost Impacts

INCOSE's Systems Engineering Handbook supports this...



- Fig 2 (ref)
 - 80% of life-cycle costs occur after Design & Development
 - But more than 85% of life-cycle costs are locked-in by the end of Development,
 - And the cost of post-Design changes escalates rapidly



Root Causes for Ops Era Cost Growth

DoD experience

- Ops Era personnel aren't involved in development, particularly in the design of maintenance & logistics
- Development and Operations have different cultures and are managed by different organizations
 - Few incentives to let Development costs grow even if they reduce Ops Era costs
 - Life-cycle cost control isn't owned by one or the other, so it's "owned" by neither
- Shortage of tools for quantifying Ops Era costs during early conceptual design, when decisions get locked in
 - Clear performance measures
 - Iterative re-validation to the targeted performance measures
- The HSI community isn't internally-integrated or externally-connected



The HSI Vision

HSI...

...Is an integrated community focused on developing more effective human/systems processes and products

- Promote total human+system performance

...Has life-cycle cost containment as its primary goal

| | |
|--------------------|---------------------------|
| – Manpower numbers | – Maintenance & Logistics |
| – Personnel skills | – Mishap avoidance |
| – Training | – Systems reworks |

...And for NASA, engages the public as human/system users

- Help demonstrate the “return on investment” of human spaceflight through engagement



Recent NASA Human Spaceflight HSI

Does NASA/JSC currently perform HSI for Human Spaceflight programs & projects?...

...Some aspects, but NASA like DoD is just starting to realize the total gain possible from HSI, and formalize its implementation

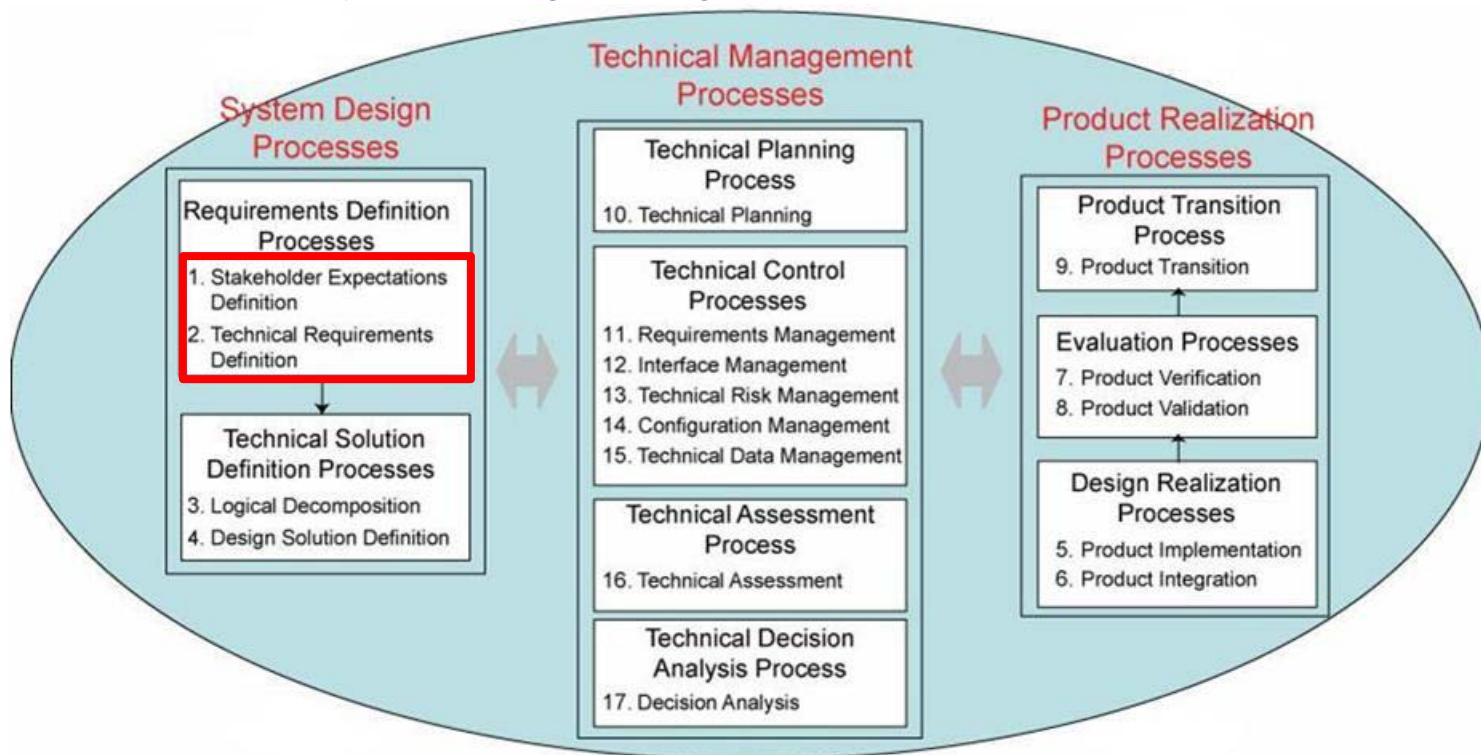


Recent NASA Human Spaceflight HSI (cont'd)

Human concerns are currently integrated into NASA Development programs primarily through Requirements and Verification

NASA agency-level document drivers

- NPR 7120.5 – Space Flight Program and Project Management Requirements
- NPR 7123.1A - Systems Engineering Processes and Requirements





Recent NASA Human Spaceflight HSI (cont'd)

HSI domains are not covered in a single requirements document, and in some cases, not at all

DoD:

DoD HSI Domains:

- Human Factors
- Environments
- Habitation
- Survivability
- Flight Medicine

...

- Safety

...

- Manpower
- Personnel
- Training

NASA Coverage:

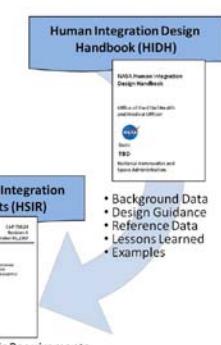
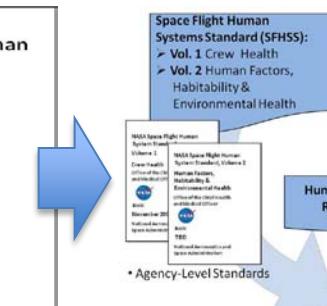
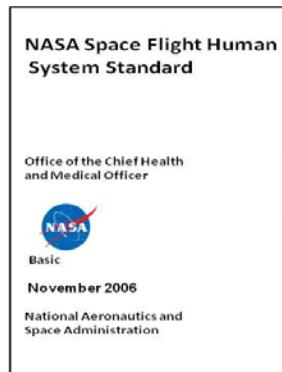
NASA-STD-3001 topics:*

- Human Factors
- Environments
- Habitation
- Survivability
- Flight Medicine

(* for Development only)



NASA Standards:



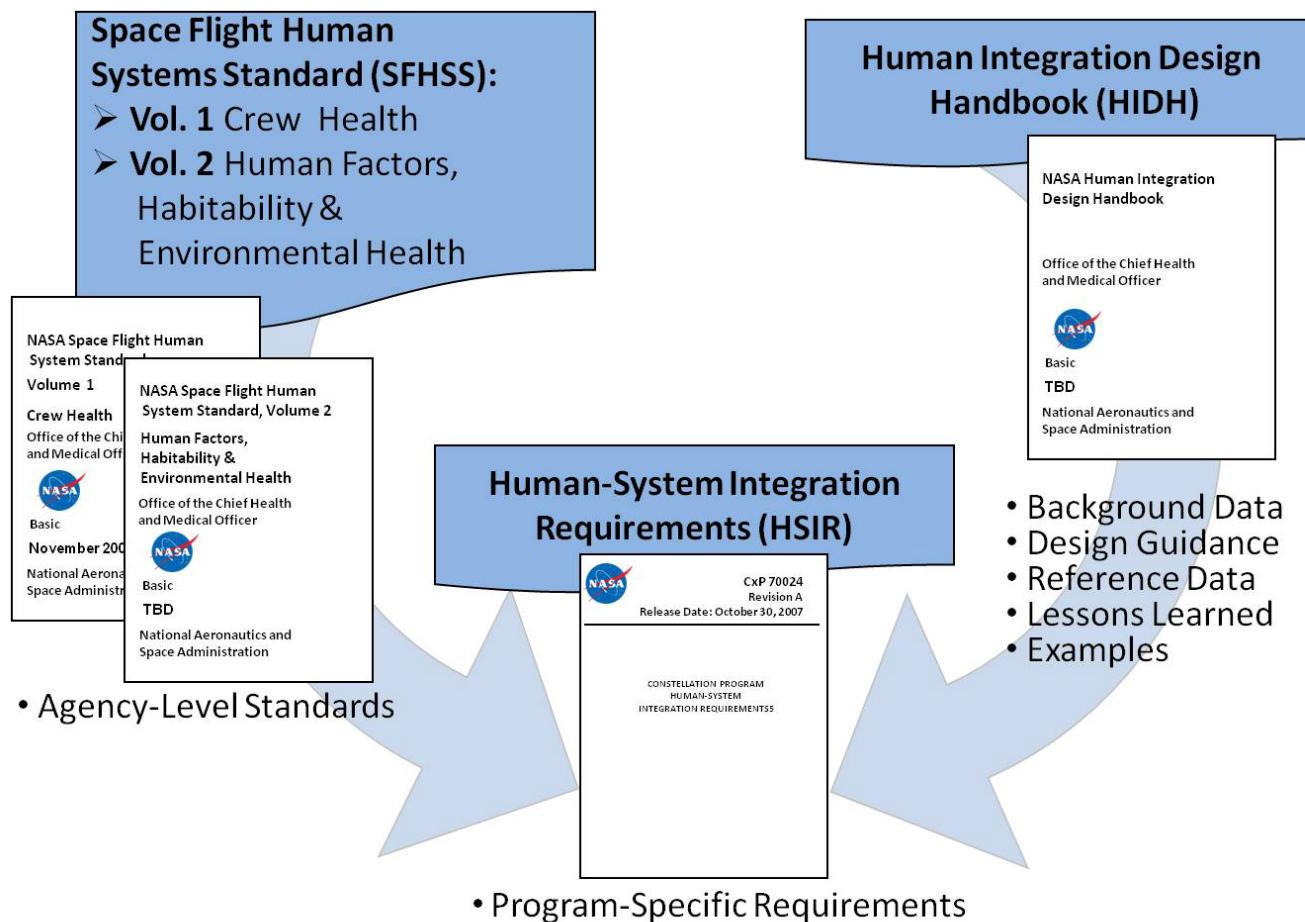
HSI is core items not well addressed
include

- Life-cycle cost containment
- Development-to-Ops validation



Recent NASA Human Spaceflight HSI (cont'd)

Program-specific requirements are developed from the standards based on the design reference mission (DRM), and invoked by the Human Rating NPR 8705.2B





Recent NASA Human Spaceflight HSI (cont'd)

What mandates “HSI” in a NASA program or project?

NPR 8705.2, Human-Rating Requirements for Space Systems:

“2.3.8 Human-System Integration Team. No later than SRR, the Program Manager shall establish a human-system integration team, consisting of astronauts, mission operations personnel, training personnel, ground processing personnel, human factors personnel, and human engineering experts, with clearly defined authority, responsibility, and accountability to lead the human-system integration (hardware and software) for the crewed space system”

No other Agency NPR calls for “HSI”

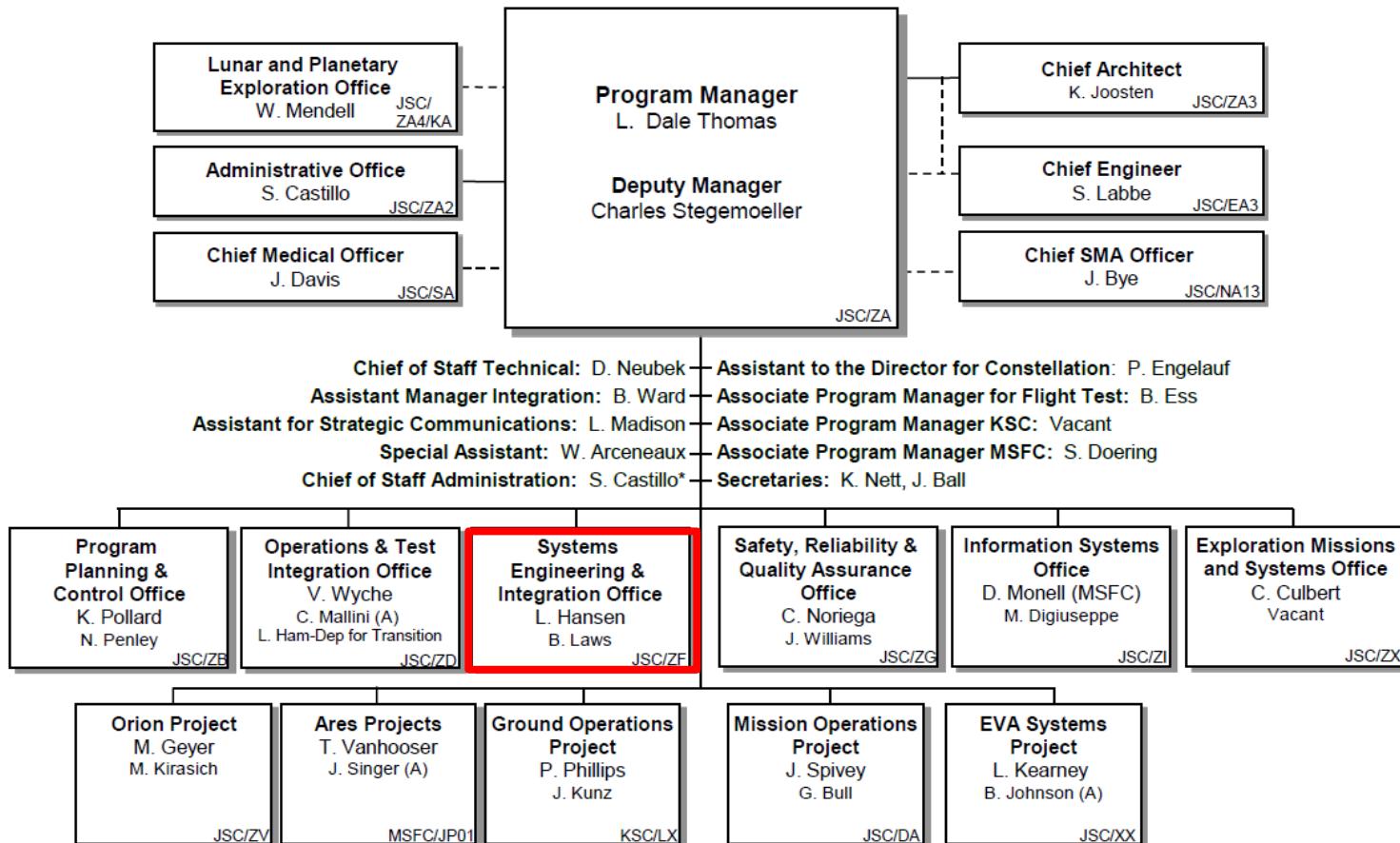
To date, this NPR has only been applied to CxP, and there were many lessons learned and best practices revealed...



The CxP Organization

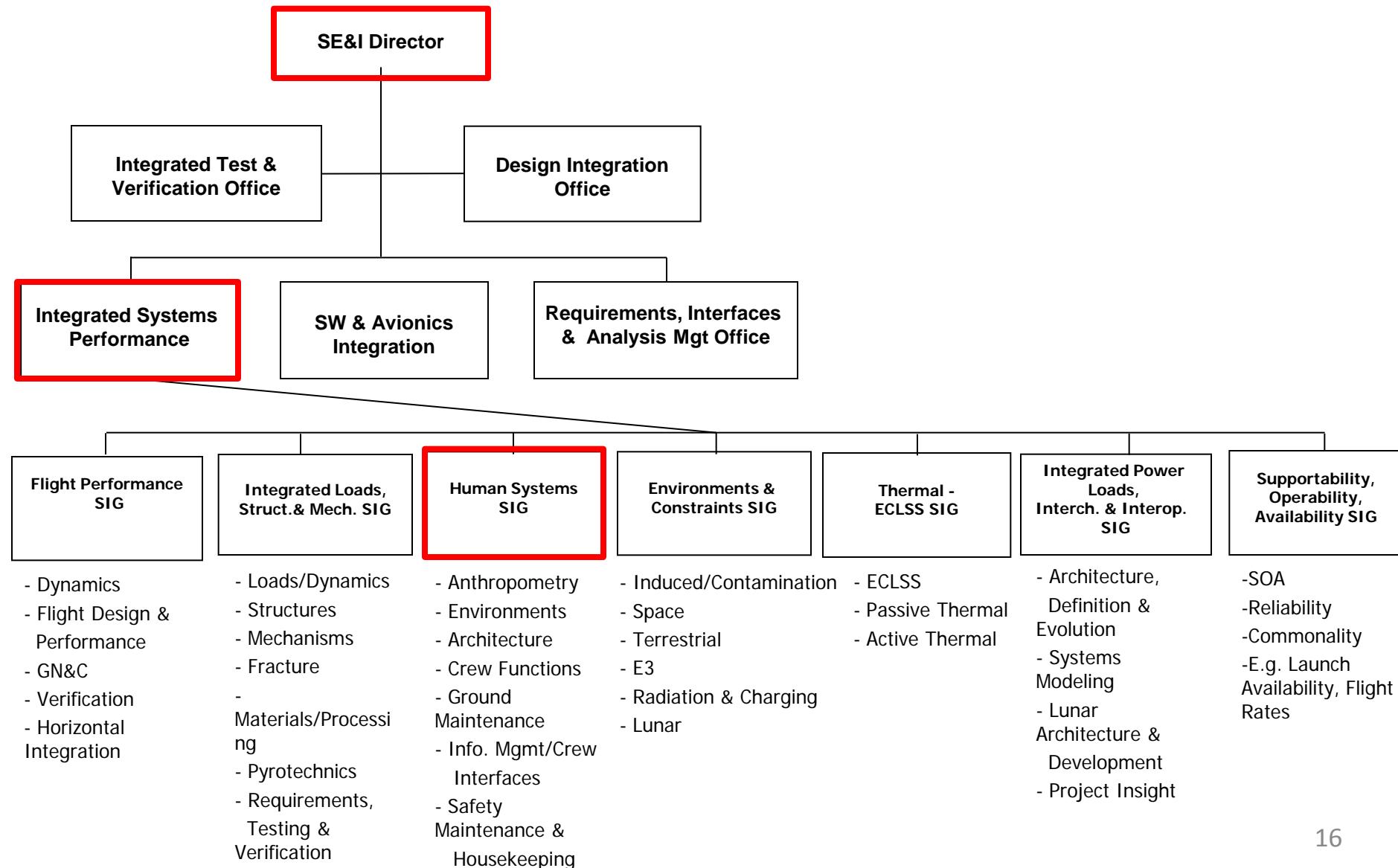


Constellation Program





Systems Engineering & Integration Organization





The Human Systems Integration Group (HSIG)

- Co-Led by Engineering and Space and Life Sciences
- HSIG managed the HSIR and was responsible for the human systems content in the Human Rating Certification Package
- Performed horizontal technical integration across the projects
- Resolution of technical issues using a community of practice (CoP) influence model
 - Consisting of Subject Matter experts and representatives from all stakeholder organizations
- CoP method was a success story in terms of bottoms-up technical integration, but not without its limitations...



Communities of Practice Facilitating Technical Issue Resolution

- Examples where Communities of Practice were used to facilitate resolution of issues:
 - Thrust Oscillation, HSIR Interpretations
- Benefits of the Community of Practice Approach:
 - Improved communication between centers
 - Enhanced Program to Project teaming and coordination led to better vertical integration.
 - Consolidation of technical positions was enabled at the discipline level and allowed the Program to provide an integrated assessment prior to Project decisions
 - The fact that the CoP did not have decisional authority led to a more appealing approach that helped gather participation in the community
 - This same fact also made it difficult to drive design changes based CoP determinations
 - No direct Technical Authority Representation
 - Human Systems Concerns often confused with Crew Office input



Communities of Practice Facilitating Technical Issue Resolution

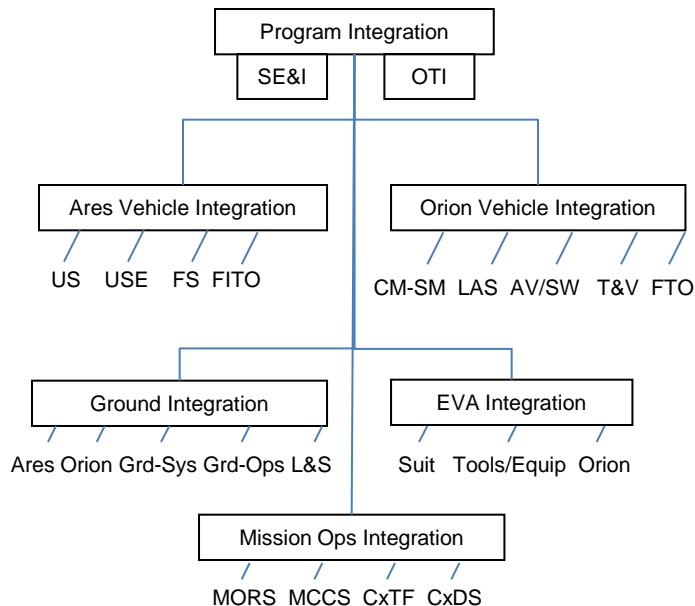
- Benefits continued
 - The collaboration of SMEs from across the agency, industry, and academia helped to:
 - Find the best expertise, regardless of location, and helped educate the community as to who the experts are and where they reside
 - Bring to bear the full breadth of this expertise within the technical disciplines to solve complicated issues
 - Disseminate expert knowledge and actually advanced the volume of knowledge in particular disciplines
- Recommendations and Best Practices
 - CoPs were effective at resolving technical integration issues
 - Participation in the CoP across all levels is necessary
 - Management must engage the CoPs directly when solving problems and seek CoP input when making decisions.
 - Organizational structure a factor here



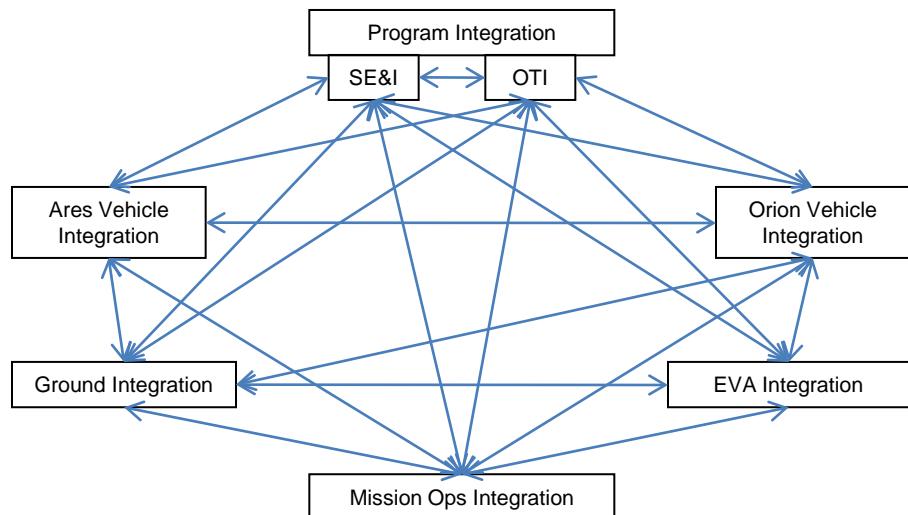
Why was the organizational info. important? Making Decisions: Process and Authority

Organizational complexity can lead to confusion, miscommunication, and unclear decision making process and delays.

What you think is working like this:



Is really working like this:



* Multiply by # of Boards, Panels, Working Groups, Discipline Groups, Stakeholders, etc

- Clear Roles, Responsibility, Accountability and Authority is a must
- Communication, Communication, Communication
- Seek the input of the appropriate integration group



Roles, Responsibilities & Decision Making in Program and Projects

- Program (or project) level organization should be established very early in a program's lifecycle with clear definitions of roles and responsibilities.
 - HSI team should be among the functions represented within the program structure
- Architect the decision making process
 - Provide clarity and support RRAA's between Program & Projects
- Board representation must be knowledgeable and empowered to act on behalf of who they represent.
- Drive down decision making to the lowest level...
 - As long as potential system to system impacts have been considered and cleared...
- One way of insuring that it to check
 - Who is Responsible?
 - Who is Accountable?
 - Who needs to be Coordinated with?
 - Who needs to be Informed?



Changing the way NASA Does Business

- NPR 8705.2, Human-Rating Requirements, was not applied as stringently to Commercial Crew Transport
 - The “mandate” for HRR compliance has softened. This may set a precedent
 - No other NPR invokes HSI
 - Unfortunately, NPRs 7120.5 and 7123.1 refer to Human Factors Engineering as a Specialty Engineering function, which implies it's optional
- There may not be a major new human spaceflight program for years
- For project-sized technology development projects, streamlining of requirements may remove HSI from consideration
- In a requirements driven model, still focused on verification
 - Need Validation to be a critical component
 - No mechanism for driving iterative design
 - How to represent HSI processes in contracts?
- Move to a standards (as opposed to requirements) driven approach with additional guidance from the Human Integration Design Handbook as a new model that allows projects to tailor more for their own purposes



Commercial Crew HSI Activities

- CHSIP is currently being developed as a how-to guide in parallel with the CHSIR requirements document
- Put the focus back on HSI being applicable to all phases, not just requirements and verifications
- Heavy emphasis on development of DRMs, Operations Concepts, Task Analysis and Functional allocation
- Want to drive more thought up front before committing to a specific design
- Requests additional products such as mock-ups and task analysis by PDR
 - keep the design in-house longer to validate concepts before committing to build it
 - more Human-in-the-Loop testing done early on and well allows us to be less requirements focused
 - less verification leads to bigger cost savings



HSI at NASA

NASA HSI Target Population:

- Promote cross-Directorate interaction in support of establishing an HSI vision, methodology, and implementation plan
 - Address the lack of formal structures that promote cross-Directorate diversity of ideas





To Achieve the HSI Vision at NASA

- Commitment from Agency level of the on the importance of HSI and its role in project design, development and operation
- Development of HSI processes, practices and tools that can be implemented on projects of varying scales, as well as commercial ventures
- Ownership of HSI activities, from development of an HSI plan through to design and operations, along with the appropriate authority and management responsibility
- Not just about adding HSI integrators to projects, the goal is to have Project Managers thinking like HSI integrators!



References

- Fig 1: Human Systems Integration (HSI) in DoD Acquisition, presentation by Nancy Dolan, January 2005 (<https://acc.dau.mil/CommunityBrowser.aspx?id=25755>)
- Fig 2: International Council on Systems Engineering (INCOSE) SE Handbook, Figure 2.4, “Committed Life-Cycle Cost against Time”
- NASA NPR 7120.5 Space Flight Program and Project Management Requirements
- NPR 7123.1A Systems Engineering Processes and Requirements
- NASA NPR 8705.2B Human Rating Requirements for Space Systems
- CxP 70024, Human Systems Integration Requirements
- FY2011 Department of Defense Human Systems Integration Management Plan
- NASA/SP-2011-6127 Vol 1 & 2 Constellation Program Lessons Learned



Back Up Charts



HSI in the Department of Defense (DoD)

HSI Target Population:

- Human-centered domains in the DoD map to multiple NASA/JSC Directorates...

DoD HSI domain examples...

- Human Factors
- Environments
- Habitation
- Survivability
- Flight Medicine
- Manpower
- Personnel
- Training
- Safety
- Occupational Health



– Logo, Air Force Research Lab, 711th Human System Wing, Human Performance Integration Directorate

NASA expertise lies in...

- Space Life Science
- Engineering
- Safety
- Mission Operations
- Flight Crew
- Budget
- Program Management
- Other areas...



HSI Domains (DoD Model)

Human Factors Engineering: Ergonomics, human factors engineering, and cognitive engineering. Pursues effective human-machine interfaces. Where practicable and cost effective, system designs shall minimize or eliminate system characteristics that require excessive cognitive, physical, or sensory skills; entail extensive training or workload-intensive tasks; result in mission-critical errors; or produce safety or health hazards.

Habitability: Establishes requirements for the physical environment (e.g., adequate volume & temperature control), personnel services (e.g., medical & food provisioning), and living conditions (e.g., berthing & hygiene) for conditions that have a direct impact on meeting or sustaining system performance or have an adverse impact on quality of life and morale.

-- from FY11 DoD HSI Management Plan



HSI Domains (DoD Model)

Environmental, Safety and Occupational Health: ESOH efforts are integrated across disciplines and into systems engineering to determine system design characteristics that can minimize the risks of acute or chronic illness, disability, or death or injury to operators and maintainers; and enhance job performance and productivity of the personnel who operate, maintain, or support the system.

Survivability: For systems with missions that might require exposure to survival threats, addresses personnel survivability issues including protection, survivability, integrity of the crew compartment, and provisions for rapid egress when the system is severely damaged or destroyed. Addresses special equipment or gear needed to sustain crew operations in the operational environment, including the suitability of equipment intended to enhance personnel survivability against threats.

-- from FY11 DoD HSI Management Plan



HSI Domains (DoD Model)

Manpower: Determines the most efficient and cost-effective mix of manpower (military, civilian, and contractor) support necessary to operate, maintain, and support (including training) the system. Analyses shall use costing tools that account for fully loaded costs.

Personnel: Defines the performance characteristics of the user population based on the system description, projected characteristics of target occupational specialties, and recruitment and retention trends. To the extent possible, systems shall not require *special cognitive*, physical, or sensory skills beyond that found in the specified user population. Systems that require specialized, hard-to-find skills impact program execution.

Training: Individual and collective training for operators, maintainers and support personnel with special emphasis on enhancing user capabilities, maintaining skill proficiencies, and reducing training costs. Maximizes use of new learning techniques, simulation technology, and instrumentation systems that provide “anytime, anyplace” training, thereby reducing demand on the training establishment.

-- from FY11 DoD HSI Management Plan



HSI 101

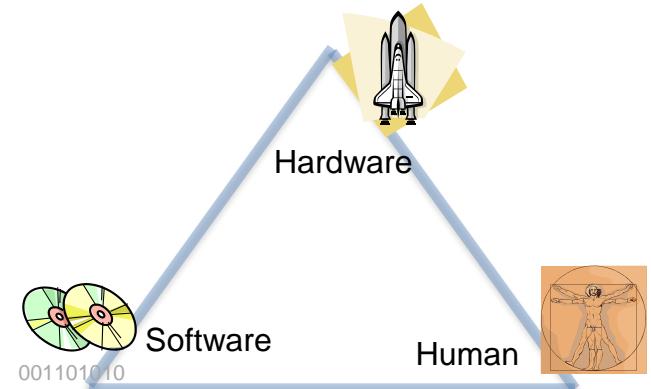
What is HSI?...

- INCOSE's Definition:

Human Systems Integration:

The interdisciplinary technical and management process(es) for integrating human considerations within and across all system elements.

HSI is an essential enabler to systems engineering practice.”



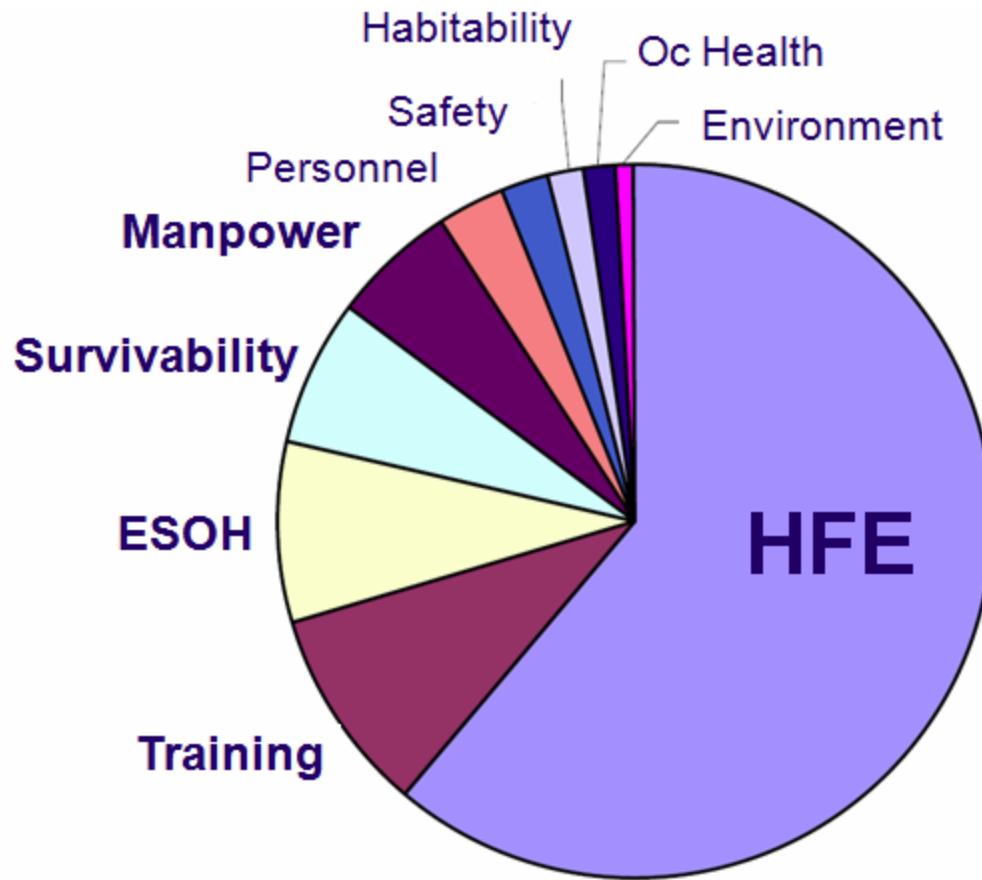
- International Council on Systems Engineering (INCOSE) definition of “HSI” as determined by their Human Systems Integration Working Group, April 2, 2007



HSI Domains (DoD Model)

- Relative frequency of HSI requirements in DoD contracts

-- from FY10 DoD HSI study



HSI-related requirements found in Government-furnished requirements documents



Frequently Asked Questions

HSI Myths & Realities:

- Myth: Systems engineers “intuitively” understand the human operator and maintainer
 - Assumptions about human capabilities, variance, and accommodation are the start of many HSI failures. It's challenging that some designers who rely on objective data assume they know all that they need to know about the people for whom their system is designed
- Myth: “We can train our way out of any design shortcomings”
 - No! This kind of thinking adds to Ops era manpower and overhead. Too, it may be a sign of willingness to accept risk. Design it right the first time! Design for Ops efficiency!
- Myth: Humans and machines are equivalent and situational awareness can be measured by simply measuring machine characteristics; technology can replace an “unreliable” human
- Myth / Reality: “Adding HSI to a program/project costs money we may not have”
 - Yes, HSI inclusion during Development may add some initial expense. However, correct application of HSI focuses on meeting mission objectives and cost-savings in the Operational era
 - This resistance to HSI inclusion comes from a lack of focus on life-cycle planning & costing
- Reality: Human Factors (HF) is not the same as HSI. HF is a subset of HSI. HSI encompasses all human-centered domains--e.g., environments, habitation, health and safety, survivability, human factors engineering, manpower, personnel capabilities, and training
 - However, it's well documented that it's most often the HF community that first embraces HSI



Frequently Asked Questions

HSI Myths & Realities: (cont'd)

- Reality: HSI is currently only mandated by the NASA's Human Rating Requirements (HRR) Document (NPR 8705.2B). Its inclusion in future NASA projects is tenuous!
 - The HRR has been applied only to major NASA programs like Constellation
 - Future small-scale programs may not have the NPR applied, and currently the commercial development effort does not need to comply with NPR 8705.2
- Reality: HSI is most successful when “process type” requirements can be levied on systems and projects (in addition to design and construction standards). However, there is currently no contractual mechanism for this
 - New methodologies will need to be developed that will allow HSI to succeed at all scales of projects and programs



An HSI Success Story

HSI Example -- F-22 Raptor engine development:

- Two contractors competed to develop the engine. Both funded through prototype development
 - One contractor was organized along HSI lines and brought 7 HSI domains to bear on their design
- Even though it cost more during Development and had slightly less performance, the down-selected engine won because of large reductions in Logistics costs brought about by quality application of HSI techniques
 - Only five hand tools are needed to service the entire engine
 - All LRUs on the engine are serviceable without having to remove any other LRU
 - Each LRU is removable within 20 minutes using only a single hand tool
 - Built in test & diagnostics
 - Serviceable by 5th to 95th percentile maintenance personnel
 - Computer-based training, etc.

